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POLARIZATION AND COLOR EFFECTS EXHIBITED BY CERTAIN DIATOMS.

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The June, 1917, issue of the *Journal of the Royal Microscopical Society,* reprints a paper by E. M. Nelson, describing polarizing effects shown by certain diatoms, in which the suggestion is made that "it may be that silex deposited by animals does not exhibit polariscope effects, while that deposited by plants, such as diatoms, will do so." Hence a satisfactory explanation of this effect seems desirable.

When plane polarized light impinges on the surface of a transparent isotropic substance so oriented as to be neither parallel nor normal to the plane of polarization, each ray is, to a greater or less extent, resolved into two polarized rays, vibrating parallel and normal to the plane of incidence, transmitted and reflected respectively. If the angle of incidence happens to correspond to the angle of maximum polarization of the reflecting substance, the effect will be almost complete, but only partial at other angles. Such reflected and refracted rays, therefore, vibrate in planes different from that of the original polarized light and would pass through an analyzer placed at right angle to the polarizer.

In using a polarizing microscope arranged to illuminate the object with parallel rays and an objective of small aperture, there is little chance of such reflected or refracted rays entering into the formation of the image, and isotropic substances appear dark between crossed prisms no matter what their shape, but the arrangement described by Mr. Nelson includes a condenser above the polarizer and an objective of fairly wide aperture, .5 N. A., under which conditions, rays reflected up to the maximum polarizing angle or their refracted components, may be transmitted through the objective, and the corresponding structural elements of the object will appear bright on a dark field, or modify the field color if a selenite film is interposed. The structure of diatoms and other minute silicious organisms is now sufficiently well understood to render it apparent that the innumerable surfaces capable of reflecting light, amply account for the polarizing effects noted, and, when illuminated under the described conditions, all diatoms, radiolaria, sponge spicules, powdered glass, or even the surface of a ground glass plate, will show bright polarization, provided they are mounted dry or in a medium of high refractive index such as realgar. When in balsam, or other media approximating their own index, the reflections are nearly or quite eliminated and most such objects become invisible, although some of the thicker polycystina and diatoms may still appear faintly contrasted with the black background, but Mr. Nelson calls attention to the interesting fact that there are certain species of diatoms that show almost equally brilliant polarizing effects when mounted in balsam.

In 1901, there was published in these PROCEEDINGS, a short communication by me, relating the results obtained from the examination of a series of diatoms in media of various refractive indices, which demonstrated that the secondary structure of certain species of *Aulacodiscus* differed from that of most diatoms by remaining equally distinct in all media, including a liquid with refractive index 1.42 to 1.43, in which diatoms generally became practically invisible. This structure has the appearance of fine granules arranged uniformly, but not symmetrically, between the larger cells constituting the primary structure, instead of over or under the latter as is the case with the perforated plates forming the secondary structure of most species of *Coscinodiscus, Triceratium* and many of *Aulacodiscus*. It is exhibited most distinctly by *Aulacodiscus formosus*, on which it can be well shown with a half inch of .60 N. A., but is present on many species of this genus, including *argus*, *rogersii*, *oregonus*, etc.; and is well displayed in a photograph of *A. sturtii* used as one of the illustrations in recent editions of Carpenter, "The Microscope and its Revelations." It may be accounted for by various hypotheses, among which, by a process of elimination, the most satisfying is to assume that the apparent granules are hermetically closed cavities, impenetrable by any medium in which the diatom is immersed.

It will be found that almost all the diatoms which exhibit bright polarization when mounted in balsam, are included in the species having this secondary structure, and, as it is not penetrated by the balsam, the same explanation will apply as to dry mounted forms.

Mr. Nelson specially mentions *Auliscus oamaruensis* as giving a most charming image with polarized light, and it is likewise one of the best forms available for elucidating the subject. This was one of the species which I formerly studied sectionally, and the markings consist of slender tubes penetrating an unusually thick silicious plate. It was not included among those examined in media of different refractive indices, but its appearance under high powers indicates that the tubules are not penetrated by the mounting medium. Its most important characteristic for the present purpose is that the markings do not extend throughout the valve but are confined to curved bands with clear interspaces and a large area of clear silica in the center. On examination with polarized light, using the highest power and aperture objective that will stand dark field illumination without halation, which in my experience, is a 4 mm. of .65 N. A., it will be noted that the polarizing effect is confined strictly to the tubular markings, while the interspaces and central area remain dark, indicating that the silica, itself, is entirely devoid of polarizing action.

Probably everyone who has mounted many slides of selected and arranged diatoms, has at times been annoyed to find that the gelatine fixative has sealed up some of the cellular structure of the diatoms, preventing penetration by the mounting medium and producing unsightly patches. However unsightly, they become interesting with polarized light as the manner in which the air filled cells light up, while the remainder of the valve is practically invisible, can leave no doubt in the mind of the observer as to the cause of the polarization effect. This was particularly noticeable on an arranged group of marine diatoms from California, which on completion, I regarded as greatly impaired by the manner in which the central portion of several valves of *Hyalodiscus maximus* had been rendered semi-opaque by the gelatine preventing complete penetration of the balsam. With polarized light, the minute air filled cells closely resembled, except in their symmetrical arrangement, the corresponding assumedly air filled cells of the secondary structure of *Aulacodiscus formosus*. A similar condition seems to exist naturally in *Hyalodiscus subtilis*, in which the so called umbilicus contains markings like the margin, but being impenetrable to balsam, remains comparatively dark when mounted in that medium, while the outer zone becomes very transparent. It is hardly necessary to add, that the central space reacts with polarized light.

Microscopists accustomed to the employment of polarized light for the purpose of determining whether a substance is isotropic or doubly refracting, have long been familiar with the effects of reflection and refraction and the necessity of avoiding them by the use of parallel illumination and mounting media of similar refraction to the material examined. In this explanation, I have confined myself to phenomena connected with the effect of such reflection and refraction on plane polarized light, but in an exhaustive treatment of the subject it would be necessary to further consider that plane polarized light, by internal total reflection or reflection from metallic surfaces, at certain angles, may become circularly or elliptically polarized, and in this form pass through the analyzing prism. This may account for the fact that light reflected from the edge of a tin foil cell, used by some preparers in mounting selected diatoms, will appear bright between crossed prisms except where such edge is parallel to the axis of either prism.

In the communication referred to above, I mentioned that some of the species of *Aulacodiscus* with the peculiar secondary structure, exhibited bright colors with ordinary transmitted light, which I was then unable to account for, but which I would now suggest may be due to optical resonance. The group of phenomena classed under this head, includes the scattering of light by particles or molecules in the atmosphere, causing the blue color of the sky, and similar but not identical effects produced by minute particles embedded in or deposited on the surface of solids. The latter phase of the subject has been extensively studied in connection with the so called "ultra microscopy" and it is unnecessary to give details here beyond stating that one of the methods of illustrating it consists of distributing minute globules of gold on a glass surface by means of electrical discharges from the end of a gold wire. Such films reflect various colors according to the size of the particles and transmit the complementary color.

Some years ago, Mr. T. C. Palmer called my attention to the possibility of depositing thin films of gold from a solution of its chloride in collodion, and gave me some of the prepared solution, with which I experimented in depositing the gold on various organic structures with the view of their elucidation, but found the film too coarsely granular to be generally satisfactory. The films, when deposited on glass, transmitted various colors, generally dark blue, and one in particular, after heating until the surface of the glass was fused, gives brilliant red and blue color effects by transmitted light, reflecting the complementary green and orange tints, due to optical resonance from the minute granules in which the metal was deposited. On examination under the microscope, the granular film shows a startling resemblance to the secondary structure of the group of Aulacodisci previously referred to, and suggests that the color shown by some of them with transmitted light may be due to the same cause. In most of these diatoms the structure is too coarse to produce color by this means, merely giving them a more or less opaque or sometimes metallic appearance, but in such forms as *A. oregonus*, in which the structure is almost as fine as on the gold film described, fairly bright colors appear, generally a bronzy green by transmitted light, and the complementary color, pink, when illuminated from above, which is as it should be, if the color is due to optical resonance from the granules of the secondary structure.

But the diatoms that show by far the brightest colors by transmitted light, are certain species of *Actinocyclus*, notably *ralfsii*, in which, as far as I am aware, no secondary structure has hitherto been noted, yet if this theory was correct they should contain such a structure and, to account for the brighter colors, it should be finer than in any species of *Aulacodiscus*. On examination, this structure was readily found to be present and particularly visible in the central blank space and wedge shaped radial segments between the coarser cellular structure of *A. ralfsii*. It is extremely delicate and will afford an excellent test for the definition of wide aperture objectives, although after finding it with an oil immersion and selecting a well-marked valve, was able to see it distinctly with a well-corrected water immersion of about 1.00 N. A., and even with an exceptionally fine dry objective of slightly less aperture.

If it should prove that this structure in *Actinocyclus* has been previously seen by others (as is usually the case with all supposedly new observations with the microscope) it will not make the slightest difference in this connection, as it was entirely unsuspected and new to me, and being found, not by accident, but because its presence was indicated theoretically, it seems to furnish rather strong evidence in favor of the correctness of the theory. As in the case of *Aulacodiscus*, *Actinocyclus* shows complementary colors with transmitted and reflected light, and fairly bright polarizing effects when mounted in balsam. On examination in a fluid of about 1.43 refractive index, it remained visible and showed bright colors by transmitted light.

All the diatoms with this peculiar secondary structure which I have as yet examined in media of various refractive indices, show brighter, higher order colors as the refractive index is increased, although the structure itself shows no change in visibility, indicating that the internal structure is combined with surface irregularities that permit the index of the medium to modify the color in accordance with the change in wave length of light transmitted through it. A hypothetical view would be that the structure corresponds to that of a foam, both with respect to the internal closed cavities, and the external surface.